Diffractive DIS: back to triple-Regge phenomenology?

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Abstract

We discuss the factorization breaking effects caused by the contribution to large rapidity gap events from DIS on secondary reggeons. Based on the triple-Regge phenomenology of hadronic diffraction dissociation, we present estimates for the flux and structure function of the f reggeon. The kinematical $x_{\mathbf{IP}}$–β correlations is shown to modify substantially the observed $x_{\mathbf{IP}}$ dependence of the diffractive structure function. The secondary reggeon and $x_{\mathbf{IP}}$–β correlation effects explain the recent H1 finding of the factorization breaking and resolve the apparent contradiction between the preliminary H1 results and predictions from the color dipole gBFKL approach. We suggest further tests of predictions for diffractive DIS from the gBFKL approach.

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1 Introduction: rapidity gaps from non-pomeron exchanges?

There is great interest in diffractive DIS $\gamma^* + p \to X + p'$ as a probe of the QCD pomeron. A convenient quantity is a diffractive structure function operationally defined as [1, 2, 3, 4]

$$(M^2 + Q^2)\frac{d\sigma^D(\gamma^* \to X)}{dt\, dM^2}\bigg|_{t=0} = \frac{\sigma_{tot}(pp)}{16\pi}\frac{4\pi^2\alpha_{em}}{Q^2}F^D(x_{\mathbf{IP}}, \beta, Q^2)\,. \tag{1}$$

Here Q^2 is the virtuality of the photon, W and M are c.m.s. energy in the photon-proton and photon-pomeron collision, $\beta = Q^2/(Q^2 + M^2)$ has the meaning of the Bjorken variable for the lepton-pomeron DIS, $x_{\mathbf{IP}} = (Q^2 + M^2)/(Q^2 + W^2) = x/\beta$ is interpreted as the fraction of the momentum of the proton carried away by the pomeron, t is the p-p' momentum transfer squared. Of special interest is the $x_{\mathbf{IP}}$-dependence of F^D, which measures the spin j (intercept) of the object exchanged in the t channel: $F_D \propto x_{\mathbf{IP}}^{2(1-j)}$. Color dipole gBFKL dynamics, one of the successful approaches to LRG (large rapidity gap) physics, predicts [4, 5, 6, 7, 8] that at the moderately small values of $x_{\mathbf{IP}}$ presently accessible at HERA the exponent $n = 2j - 1$ must depend on flavor, β and, for longitudinal photons, on Q^2 in defiance of the often assumed Ingelman-Schlein-Regge factorization [1, 2, 3, 9, 10, 11]. The rise of the exponent n at small $x_{\mathbf{IP}}$ is of special interest as it derives from the intrusion of hard scattering effects into soft interaction amplitudes which is a very specific signature of the gBFKL dynamics [12, 13, 14].

One of the signals of the Regge factorization breaking in the gBFKL approach is a *rise* of $n(x_{\mathbf{IP}}, \beta)$ towards small β [6]. Recently the H1 collaboration reported the first evidence for the factorization breaking. However, H1 finds a *decrease* of $n(x_{\mathbf{IP}}, \beta)$ at small β [15]. Is that compatible with the gBFKL approach?

Although only the pomeron exchange survives at $x_{\mathbf{IP}} \to 0$, the range of the presently accessible $x_{\mathbf{IP}}$ is limited. Furthermore, by virtue of the kinematical relationship $x_{\mathbf{IP}} = x/\beta$, the small-$\beta$ data correspond to the larger values of $x_{\mathbf{IP}}$. Although the confirmation of the H1 effect by the ZEUS collaboration is pending [16], one must seriously examine the possibility [17, 18] that the H1 effect is due to an admixture of the non-pomeron exchanges. Indeed, whereas for the pure gBFKL pomeron exchange we expect $n \sim 1.2$ for the HERA kinematics

([6, 8] and see below), for the pure pion exchange $n \sim -1$. A comparison of the pion and pomeron exchanges in [19] has shown that the pion contribution becomes comparable to the pomeron contribution at $x_{\mathbb{P}} \sim 0.1$. Consequently, the exponent n must decrease from $n \sim 1.2$ at small $x_{\mathbb{P}}$ down to $n \sim -1$ in the pion exchange dominated region of larger $x_{\mathbb{P}}$.

These two extreme cases demonstrate a potential sensitivity of $n(x_{\mathbb{P}}, \beta)$ to the non-pomeron exchanges. In a more accurate treatment one must allow for the f, ω, ρ, A_2 reggeon exchanges. In the color dipole gBFKL approach diffractive DIS is controlled by predominantly soft interactions of large size color dipoles in the photon [4, 5, 6]. For instance, it has been argued that the so-called triple-pomeron coupling changes little from real photoproduction, $Q^2 = 0$, to DIS at large Q^2 [20]. Similar dominance by soft pomeron interactions holds in other popular models of diffractive DIS [3]. Therefore, we can gain certain insight from the familiar triple-Regge phenomenology of diffraction dissociation of hadrons [21, 22] and Regge fits to total cross sections [23]. The purpose of the present communication is the quantitative evaluation of the reggeon exchange contribution to F^D. In conjunction with the kinematical $x_{\mathbb{P}} - \beta$ correlation, we find quite a strong impact of reggeon exchanges on the effective exponent n which is compatible with the H1 finding. From the practical point of view, better understanding of the pomeron-reggeon-pion exchange content of diffractive DIS is imperative for the interpretation of the large-$x_{\mathbb{P}}$ data to come soon from the Leading Proton Spectrometer of ZEUS. We discuss simple tests of the reggeon-exchange mechanism of the H1 effect and strategies for separation of the pure pomeron exchange. We also point out the possibility of testing the predictions from color dipole model of substantial intrusion of hard gBFKL exchange to soft processes.

2   Evaluation of the reggeon exchange parameters

First, we recall the basics of the triple-Regge phenomenology of hadronic diffraction. The triple-Regge diagrams for $pp \to pX$ are shown in Fig. 1 and give (for the sake of brevity we focus on $t = 0$, for detailed formulas see [1, 21, 22])

$$M^2 \frac{d\sigma^D}{dt\, dM^2} = \frac{1}{16\pi} \left[g_{\mathbb{P}}^2(t) |\xi_{\mathbb{P}}(t)|^2 \sigma_{tot}^{p\mathbb{P}} x_{\mathbb{P}}^{2(1-\alpha_{\mathbb{P}}(t))} + g_f^2(t) |\xi_f(t)|^2 \sigma_{tot}^{pf} x_{\mathbb{P}}^{2(1-\alpha_R(t))} \right.$$

$$+ 2g_{\mathbf{P}}(t)g_f(t)\mathrm{Re}[\xi_{\mathbf{P}}(t)\xi_f^*(t)]\Sigma^{\mathbf{P}f}x_{\mathbf{P}}^{2-\alpha_{\mathbf{P}}(t)-\alpha_f(t)} + ...\Big] =$$

$$\phi_{\mathbf{P}}\sigma_{tot}^{p\mathbf{P}} + \phi_f x_{\mathbf{P}}\sigma_{tot}^{pf} + \Phi_{\mathbf{P}f}x_{\mathbf{P}}^{\frac{1}{2}}\Sigma^{\mathbf{P}f}..., \qquad (2)$$

where $\phi_{\mathbf{P}}/x_{\mathbf{P}}$ and ϕ_f have the meaning of fluxes of pomerons and reggeons in the proton [2, 3] and $\sigma_{tot}^{p\mathbf{P}}$ and σ_{tot}^{pf} have the meaning of the proton-pomeron and proton-reggeon total cross sections, $\xi_{\mathbf{P},f} = i - \cot(\frac{1}{2}\pi\alpha_{\mathbf{P},f})$ is the signature factor, the residues $g_{\mathbf{P}}$ and g_f of the pomeron and f exchanges can be determined from the crossing-even part of the $pp, \bar{p}p$ total cross section

$$\frac{1}{2}(\sigma_{tot}^{pp} + \sigma_{tot}^{\bar{p}p}) = g_{\mathbf{P}}^2(0) + g_f^2(0)\left(\frac{s_0}{s}\right)^{1-\alpha_R}, \qquad (3)$$

where the standard but still arbitrary choice is $s_0 = 1\,\mathrm{GeV}^2$. In the $\mathbf{P}$-f interference term one encounters the amplitude of forward diffraction dissociation of the pomeron into f reggeon and $\Sigma^{\mathbf{P}f} = \mathrm{Im}A(p\mathbf{P} \to pf)/M^2$. For the sake of simplicity, formulas (2) and (3) were written for $t = 0$ and in the approximation $\alpha_{\mathbf{P}}(0) = 1$ and $\alpha_R(0) = \frac{1}{2}$, the former has been the common assumption (and deficiency) of all works [21, 22] on the triple-Regge analysis of hadronic diffraction, we comment more on that below.
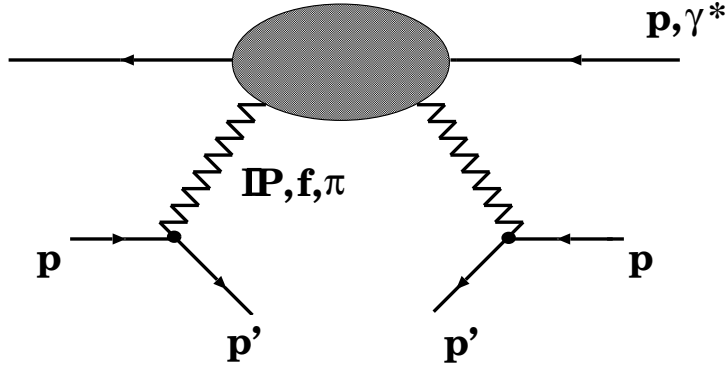

Figure 1: *Reggeon-exchange diagrams for $pp \to pX$.*

One must also include the numerically important pion exchange term

$$M^2\frac{d\sigma^D(pp \to pX)}{dt\,dM^2} = \frac{g_{\pi NN}^2 x_{\mathbf{P}}^2}{(4\pi)^2}\frac{G_\pi^2(x_{\mathbf{P}},t)|t|}{(|t| + m_\pi^2)^2}\sigma_{tot}^{\pi N}, \qquad (4)$$

where $G_\pi(x_{\mathbf{P}},t)$ is the πNN form factor. The exchanged pions are not far off-mass shell and using the πN total cross section for real pions leads to a very good quantitative description

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of the related charge exchange $pp \to nX$ ([24, 25, 26] and references therein). For diffractive DIS the similar substitution

$$\sigma_{tot}^{\pi N} \implies \sigma_{tot}^{\gamma^* \pi} = \frac{4\pi^2 \alpha_{em}}{Q^2} F_2^\pi(\beta, Q^2) \tag{5}$$

with the Drell-Yan determinations of the pion structure function is a viable approximation. For instance, it provides a parameter-free description of the experimentally observed $\bar{u} - \bar{d}$ asymmetry in the proton ([26, 27] and references therein).

The f-exchange contribution to diffraction of protons is not so well determined, the parameter $G_{ff\mathbf{P}} = \frac{1}{8\pi} g_f^2(0) \sigma_{tot}^{pR}$ varies from $7.2\,\mathrm{mb(GeV)^{-2}}$ and $13.2\,\mathrm{mb(GeV)^{-2}}$ in the two solutions of Kazarinov et al. [21] to $\approx 30\,\mathrm{mb(GeV)^{-2}}$ by Field and Fox [22]. The Regge fits to total cross sections are in much better shape [23] and give $g_f^2(0) \approx 80mb$, for the ω exchange g_ω^2 is one order in magnitude smaller, the residues for the ρ, A_2 are still smaller. Then, if we stick to the reggeon flux normalization (2), the above cited determinations of $G_{ff\mathbf{P}}$ would correspond to

$$\sigma_{tot}^{pf} = \frac{8\pi G_{ff\mathbf{P}}}{g_f^2(0)} = \lambda_f \sigma_{tot}^{\pi N} = (1 - 4)mb\,, \tag{6}$$

which is an order in magnitude smaller than the natural scale $\sigma_{tot}^{\pi N} \approx 25$ mb. Consequently, there emerges a small parameter $\lambda_f = (0.04 - 0.15)$ and the educated guess for the reggeon structure function in the substitution (5) would be

$$F_2^f(\beta, Q^2) \sim \lambda_f F_2^\pi(\beta, Q^2)\,. \tag{7}$$

Because the β dependence of the reggeon structure function is basically unknown, (7) must be regarded as a useful benchmark evaluation.

From the comparison of different triple-Regge fits [21, 22] one concludes that allowance for the $\mathbf{P}$-f interference lowers the fitted value of $G_{ff\mathbf{P}}$. In hadronic interactions the diffraction dissociation amplitudes are strongly suppressed compared to elastic scattering amplitudes, which suggests $\Sigma^{\mathbf{P}f} \ll \sigma_{tot}^{p\mathbf{P}}, \sigma_{tot}^{pf}$ and triple-Regge fits with weak $\mathbf{P}$-f interference are more preferable. In diffractive DIS, the $\mathbf{P}$-f interference term gives rise to an unusual off-diagonal structure function associated with the imaginary part of the $\gamma^* \mathbf{P} \to \gamma^* f$ forward scattering amplitude. It has been argued that for hadronic targets such an off-diagonal

structure function is strongly suppressed because the quark number and momentum integrals must vanish for the orthogonality of states [27]. Then, our educated guess is that in diffractive DIS the $\mathbb{P}$-f interference must be negligibly small and the large λ_f fit [22] is preferred.

There is one more reason for considering the larger λ_f. Namely, an obvious deficiency of the available triple-Regge fits [21, 22] is their assumption $\alpha_{\mathbb{P}}(0) = 1$, whereas according to the Donnachie-Landshoff fits to hadronic total cross sections $\alpha_{\mathbb{P}} = 1 + \epsilon \approx 1.08$ is the more appropriate one [23]. For the Donnachie-Landshoff value of $\alpha_{\mathbb{P}}(0)$ the pomeron contribution in the triple-Regge expansion (2) will decrease $\propto x_{\mathbb{P}}^{-2\epsilon}$. In order to reproduce the same observed diffraction cross section, this decrease of the pomeron contribution with increasing $x_{\mathbb{P}}$ ought to be compensated for by the enhancement of the f-exchange contribution by about factor 2 compared to the determinations in [21, 22]. Therefore, our educated guess for the f-reggeon contribution in the triple-pomeron expansion (8) for diffractive DIS is $\lambda_f \approx 0.3$. Judging from evaluations of the Q^2 dependence of the triple-pomeron coupling [20], this estimate for λ_f is good within the factor 2.

To conclude this discussion we mention that one must not interpret the small λ_f as a strong suppression of the structure function of the strongly off-mass shell reggeized f-meson because the factor λ_f can as well be reabsorbed into the definition of the reggeon flux. Neither pomerons nor reggeons can be treated as particles, the normalizations of fluxes (2) and of the pomeron-particle and reggeon-particle cross sections $\sigma_{tot}^{p\mathbb{P}}, \sigma_{tot}^{pf}$ are arbitrary, only the products $g_{\mathbb{P}}^2 \sigma_{tot}^{p\mathbb{P}}$ and $g_f^2 \sigma_{tot}^{pf}$ are well defined. For instance, in the very definition of the Regge residue g_f in (3) there is a fundamental uncertainty with the choice of s_0.

The pomeron exchange contribution to diffractive DIS has been evaluated directly in terms of the color dipole gBFKL cross section [6] and the agreement with the HERA data on F^D is very good, see a detailed comparison between the theory and experiment in [28].

3   The triple-Regge parameterization for diffractive DIS

In (2) we focused on $t = 0$. At HERA one rather measures the t-integrated cross section, which includes the charge exchange $\gamma^* p \to Xn$ on top of the π^0 exchange contribution

$\gamma^* p \to X p$, there is also a certain admixture of double diffraction, which is marginal for the purposes of the present discussion, see the analysis in [29]. Within the present uncertainty in the parameter λ_f one can neglect the difference in the t-dependence of the pomeron and reggeon cross section. Then, our triple-Regge parameterization for the observed mass spectrum is

$$(M^2 + Q^2)\frac{d\sigma^D(\gamma^* \to X)}{dM^2} = \frac{4\pi^2\alpha_{em}}{Q^2}\Phi_D^{(3)}(x_{\mathbb{P}}, \beta, Q^2) =$$

$$\frac{4\pi^2\alpha_{em}}{Q^2} \cdot \left\{ \frac{\sigma_{tot}^{pp} G_p^2(m_p^2 x_{\mathbb{P}}^2)}{16\pi B_{3\mathbb{P}}} \left[(1 + R_{LT})\phi_{\mathbb{P}}^{sea}(x_{\mathbb{P}})F_{sea}^{\mathbb{P}}(\beta, Q^2) + \frac{B_{3\mathbb{P}}}{B_{el}}\phi_{\mathbb{P}}^{val}(x_{\mathbb{P}})F_{val}^{\mathbb{P}}(\beta, Q^2) \right.\right.$$

$$\left. + \phi_{\mathbb{P}}^L(x_{\mathbb{P}}, Q^2)F_{L,val}^{\mathbb{P}}(\beta, Q^2) \right]$$

$$\left. + \frac{g_f^2 G_p^2(m_p^2 x_{\mathbb{P}}^2)}{8\pi B_{3\mathbb{P}}}\lambda_f x_{\mathbb{P}} F_2^\pi(\beta, Q^2) + 3x_{\mathbb{P}}^2 f_\pi(x_{\mathbb{P}})F_2^\pi(\beta, Q^2) \right\}, \tag{8}$$

where $G_p(q^2)$ is the charge form factor of the proton and $G_p^2(q^2)$ gives an estimate for the survival of the proton in the final state at the (longitudinal) momentum transfer $q = m_p x_{\mathbb{P}}$. For the numerical estimations, we take $B_{3\mathbb{P}} = 6\,\mathrm{GeV}^{-2}$ for the diffraction slope of the sea term and $B_{el} = 2B_{3\mathbb{P}}$ for the valence term, $\sigma_{tot}^{pp} = 40\,\mathrm{mb}$, $g_f^2/(8\pi B_{3\mathbb{P}}) \approx 1.3$. The pomeron contribution has been described in [6, 8]. The parameterizations of the valence and sea structure functions for $Q^2 \sim 10\,\mathrm{GeV}^2$ are $F_{sea}^{\mathbb{P}}(\beta, Q^2) = 0.063(1-\beta)^2$, $F_{val}^{\mathbb{P}}(\beta, Q^2) = 0.27\beta(1-\beta)$, the flux factors

$$\phi_{\mathbb{P}}(x_{\mathbb{P}}) = \left(\frac{x_0}{x_{\mathbb{P}}}\right)^{p_1} \left(\frac{x_{\mathbb{P}} + p_3}{x_0 + p_3}\right)^{p_2} \tag{9}$$

are normalized to unity at $x_{\mathbb{P}} = x_0 = 0.03$, for the valence component of the pomeron $p_1 = 0.569, p_2 = 0.4895, p_3 = 1.53 \cdot 10^{-3}$ ($\phi_{\mathbb{P}}^{val}(x_{\mathbb{P}})$ of the present paper is $\phi_{\mathbb{P}}(x_{\mathbb{P}})$ of Ref. [6]), and for the sea component of the pomeron $p_1 = 0.741, p_2 = 0.586, p_3 = 0.8 \cdot 10^{-3}$ ($\phi_{\mathbb{P}}^{sea}(x_{\mathbb{P}})$ of the present paper is $f_{\mathbb{P}}(x_{\mathbb{P}})$ of Ref. [6]). We included also the longitudinal cross section as calculated and parameterized in [8] (the parameterization of [8] was intended to reproduce the gross features of $\Phi_{\mathbb{P}}^L$ and $F_{L,val}^{\mathbb{P}}$ only at $x_{\mathbb{P}} \gtrsim 10^{-4}$); in the sea region $R_{LT} = \sigma_L^D/\sigma_T^D = 0.2$, the longitudinal valence component $F_{L,val}^D$ is small apart from the narrow region of $\beta \gtrsim 0.8$, it takes over completely at $\beta \gtrsim 0.9$.

The pion contribution enters the diffractive DIS as measured at HERA with the extra isospin factor 3, because the both diffractive $\gamma^* p \to X p$ and charge-exchange $\gamma^* p \to X n$

channels are included in the observed cross section at the present stage of the H1 and ZEUS detectors. The pion structure function is borrowed from [30], a convenient parameterization for the flux of pions good to $\approx 10\%$ up to $x_{\mathbb{P}} \lesssim 0.8$ (at larger $x_{\mathbb{P}}$ this flux nearly vanishes anyway) is

$$f_\pi(x_{\mathbb{P}})x_{\mathbb{P}}^2 = \frac{g_{\pi NN}^2 x_{\mathbb{P}}^2}{(4\pi)^2} \int_{m_p^2 x_{\mathbb{P}}^2}^{\infty} d|t| \frac{G^2(t)|t|}{(|t| + m_\pi^2)^2} \approx x_{\mathbb{P}}^2 0.66(1 + 5.7\sqrt{x_{\mathbb{P}}})(1 - x_{\mathbb{P}})^{3.3} . \qquad (10)$$

At small β the Q^2 evolution of the pomeron and pion structure functions must be similar [5, 6] and the gross features of $x_{\mathbb{P}}$ dependence in (9) must not change much with Q^2. The effects of non-GLDAP evolution at $\beta \to 1$ [7, 17] are marginal for the purposes of the present exploratory study and we present all the results for $Q^2 = 10 \, \mathrm{GeV}^2$.

4   The reggeon-exchange driven factorization breaking: the numerical estimates

In Fig. 2 we show the $x_{\mathbb{P}}$ dependence of $\Phi_D^{(3)}(x_{\mathbb{P}}, \beta, Q^2)$ defined by Eq. (8) for several values of β. Unless specified otherwise, the reggeon contribution is always evaluated for $\lambda_f = 0.3$. The pomeron-pion-reggeon content of $\Phi_D^{(3)}(x_{\mathbb{P}}, \beta, Q^2)$ varies with β little. Because our parameterization for $F_{sea}^{\mathbb{P}}(\beta, Q^2)$ is flat at small β whereas the GRV pion structure function rises towards small β, the pion and reggeon effects are enhanced at small β slightly, which may or may not survive for different pion and pomeron structure function which for small β are still a theoretical guess. Typically, the reggeon contribution becomes noticeable at

$x_{\mathbb{P}} \sim 0.01$, the pion contribution dominates at $x_{\mathbb{P}} \gtrsim 0.1$. The combined reggeon and pion contributions substantially alter the trend of the $x_{\mathbb{P}}$ dependence already at $x_{\mathbb{P}} \gtrsim 0.02$. Their effect is best seen in the exponent of the local $x_{\mathbb{P}}$ dependence

$$n(x_{\mathbb{P}}, \beta) = 1 - \frac{d \log \Phi_D^{(3)}(x_{\mathbb{P}}, \beta, Q^2)}{d \log x_{\mathbb{P}}}$$

shown in Figs. 3 and 4. In Fig. 3 we show this exponent $n_{\mathbb{P}}(x_{\mathbb{P}}, \beta)$ for the pure pomeron exchange and for the unconstrained β and $x_{\mathbb{P}}$ dependence. In the specific color dipole
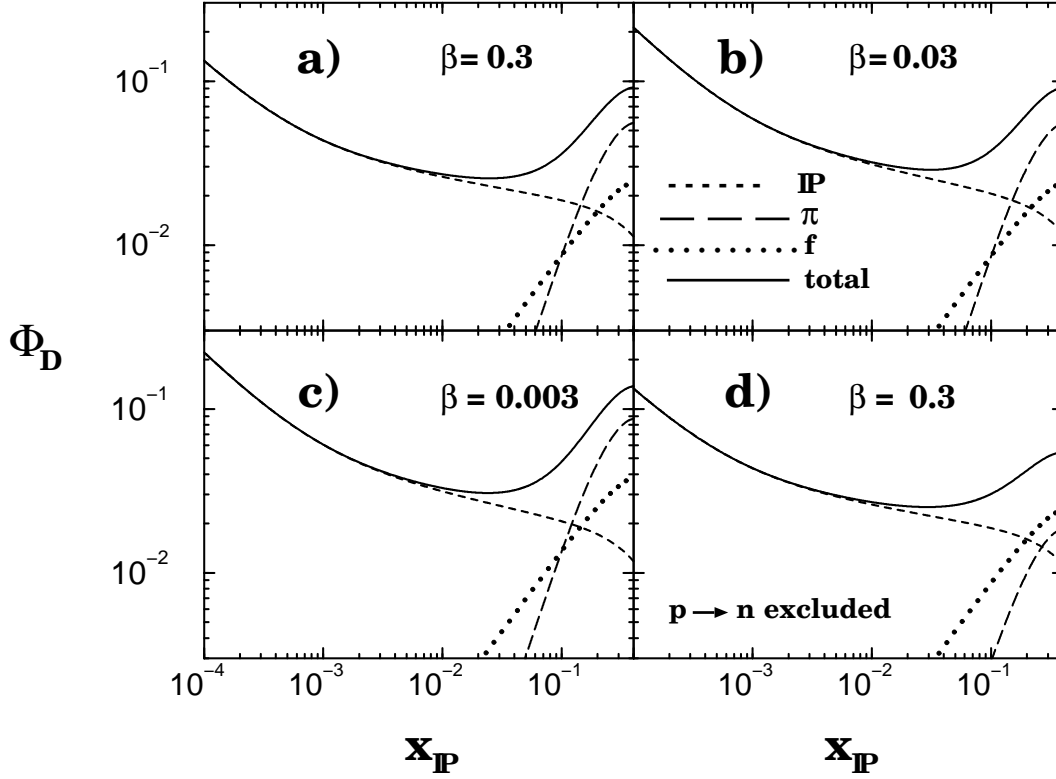
Figure 2: - *The pomeron-reggeon-pion exchange decomposition of the triple-Regge expansion for $\Phi_D^{(3)}(x_{\mathbb{P}}, \beta, Q^2)$. The f-exchange is evaluated for $\lambda_f = 0.3$. The boxes (a), (b), (c) are for $\beta = 0.3, 0.03, 0.003$, respectively. The box (d) is for the LPS trigger which excludes the contribution from the charge exchange reaction $\gamma^* p \to Xn$.*

model [31, 14] the rightmost j-plane singularity of the gBFKL pomeron has an intercept $\alpha_{\mathbb{P}}(0) = 1.4$, and at very high energies and/or very small $x, x_{\mathbb{P}}$ all cross sections, for soft and hard processes alike, must exhibit the universal $\propto s^{\alpha_{\mathbb{P}}(0)}, x^{-\alpha_{\mathbb{P}}(0)}$ behavior. Indeed, at larger $x_{\mathbb{P}}$ the nonperturbative soft pomeron dominates and n is small, with the rising contribution from the gBFKL pomeron at very small $x_{\mathbb{P}}$ the exponent $n(x_{\mathbb{P}}, \beta)$ tends to $n = 2\alpha_{\mathbb{P}}(0) - 1 = 1.8$, although very small $x_{\mathbb{P}}$ beyond the HERA range is needed to reach this limiting value [1] [14]. For the soft pomeron dominated mechanisms of diffractive DIS $n(x_{\mathbb{P}}, \beta)$ is flat vs. $x_{\mathbb{P}}$ [3]. Notice, that variations of $n(x_{\mathbb{P}}, \beta)$ with $x_{\mathbb{P}}$ are quite substantial, stronger than variations with β. The latter derives from the factorization breaking difference

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[1] The exponents p_1 for the sea and valence fluxes are close to but still unequal to $2(\alpha_{\mathbb{P}}(0) - 1) = 0.8$, because the simple parameterization (9) was intended to describe the flux functions only at $x \gtrsim 10^{-5}$ with an emphasis on the still larger values of $x_{\mathbb{P}}$ accessible at HERA.

of $\phi_{\mathbf{IP}}^{val}(x_{\mathbf{IP}})$ and $\phi_{\mathbf{IP}}^{sea}(x_{\mathbf{IP}})$ and from the dominance of the longitudinal cross section at $\beta \gtrsim$ 0.9, which is the higher twist effect and is less important at larger Q^2 [8]. In Fig. 4
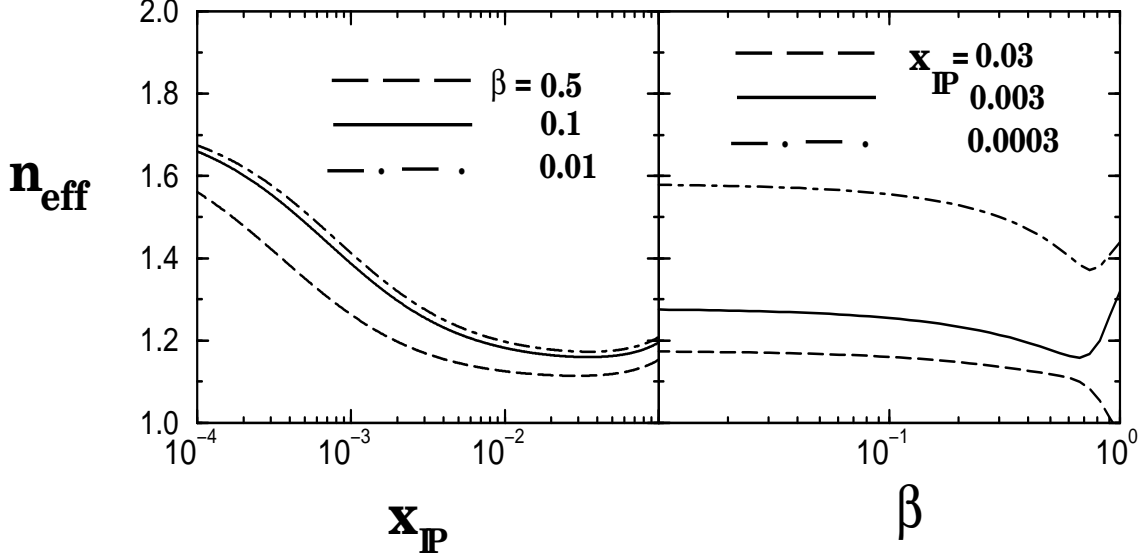

Figure 3: *The exponent $n_{\mathbf{IP}}(x_{\mathbf{IP}}, \beta)$ for the pure pomeron exchange. In the left box we show only $\beta > 0.01$, at smaller β the exponent $n_{\mathbf{IP}}(x_{\mathbf{IP}}, \beta)$ levels off.*

we present predictions from the full triple-Regge expansion (8). In the typical experimental situation the smaller values of β imply the larger values of $x_{\mathbf{IP}}$ which enter the fit $\Phi^D \propto x_{\mathbf{IP}}^{1-n}$. Then, the gross features of this $x_{\mathbf{IP}}$-β correlation are reproduced by

$$\langle x_{\mathbf{IP}} \rangle \sim \frac{\langle x(\beta) \rangle}{\beta} . \tag{11}$$

The somewhat different range of x is spanned at different β, for the purposes of our crude estimates we can take $\langle x(\beta) \rangle = 10^{-3}$ [33, 28, 15]. The H1 determinations of the exponent n correspond to $n_{eff}(\langle x \rangle, \beta) = n(x_{\mathbf{IP}} = \frac{\langle x \rangle}{\beta}, \beta)$ and the $x_{\mathbf{IP}}$ dependence of $n(x_{\mathbf{IP}}, \beta)$ shown in Fig. 3 transforms into the effective β dependence of $n_{eff}(\langle x \rangle, \beta)$ shown in Fig. 4. In order to see the impact of the $x_{\mathbf{IP}}$-β correlation, focus for simplicity on $\beta \ll 1$ and suppress the pion effects. For the GRV pion structure function $F^\pi(\beta, Q^2) \approx C F_{se}^{\mathbf{IP}}(\beta, Q^2)$ with $C \sim 10$ and the both structure functions are approximately flat for $\beta \gtrsim 10^{-2} - 10^{-3}$. The Donnachie-Landshoff fits five $g_\omega^2 / \sigma_{tot}^{pp} \approx 2$. Then $\Phi_D^{(3)} \propto \phi_{\mathbf{IP}}^{sea}(x_{\mathbf{IP}}) + 4C\lambda_f x_{\mathbf{IP}}^{1-\alpha_R}$ and

$$n_{eff}(\langle x \rangle, \beta) = n_{\mathbf{IP}}(x_{\mathbf{IP}}, \beta) \frac{\phi_{\mathbf{IP}}^{sea}(x_{\mathbf{IP}})}{\phi_{\mathbf{IP}}^{sea}(x_{\mathbf{IP}}) + 4C\lambda_f x_{\mathbf{IP}}^{1-\alpha_R}}$$
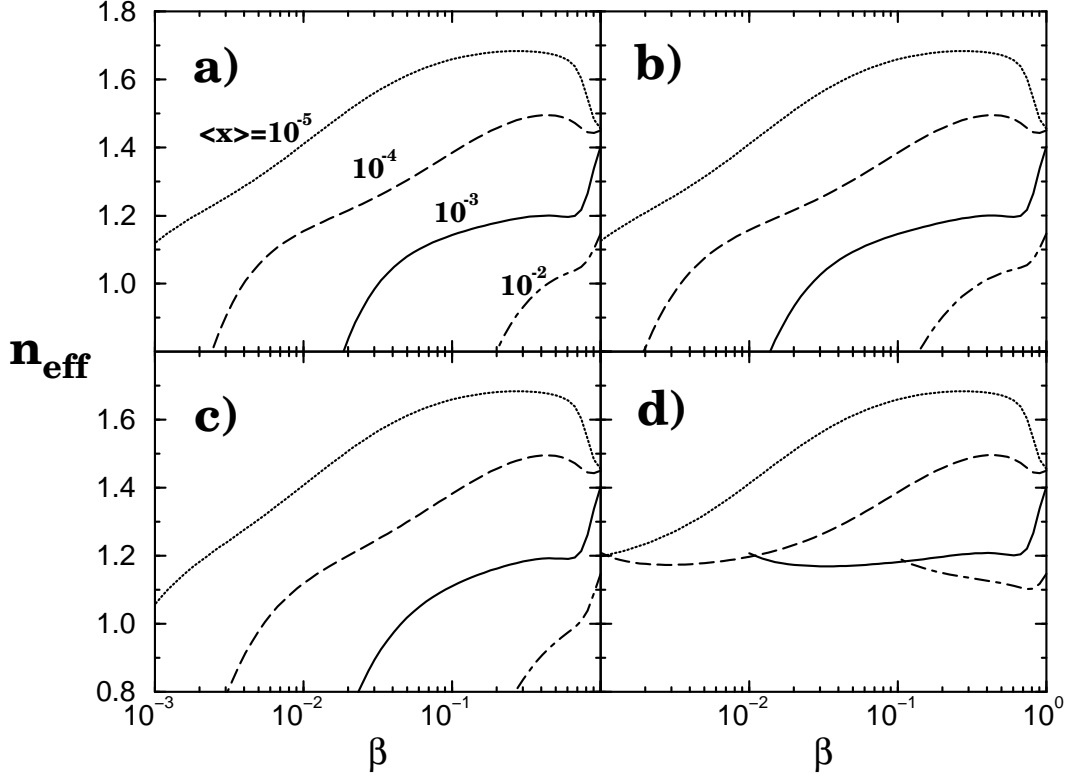
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Figure 4: - *The exponent $n_{eff}(\langle x\rangle, \beta)$ evaluated subject to the correlation (11) for different values of $\langle x\rangle$ which are the same for all the boxes: (a) the results for $\lambda_f = 0.3$ and no forward nucleon trigger; (b) the same as (a) but for the LPS trigger which excludes the $\gamma^* p \to Xn$ contribution; (c) the same as (a) but for $\lambda_f = 0.6$; (e) the exponent $n_{eff}(\beta)$ for the pure pomeron exchange.*

$$-\left(\frac{\langle x\rangle}{\beta}\right)^{1-\alpha_R} \frac{4C\lambda_f(1-\alpha_R)}{\phi_{\mathbf{IP}}^{sea}(x_{\mathbf{IP}}) + 4C\lambda_f x_{\mathbf{IP}}^{1-\alpha_R}}, \tag{12}$$

where $x_{\mathbf{IP}} = \langle x\rangle/\beta$ is understood everywhere, we used that explicitly in front of the major correction term. Evidently, the f-reggeon contribution depletes n_{eff} and the smaller is β the stronger is the depletion of n_{eff}. The effect of pions is similar. In Fig. 4a we show $n_{eff}(\langle x\rangle, \beta)$ for the triple-Regge expansion (8) with $\lambda_f = 0.3$. In Fig. 4b we also show $n(x_{\mathbf{IP}}, \beta)$ for diffractive DIS measured with the Leading Proton Spectrometer (LPS) trigger which excludes the charge exchange $\gamma^* p \to Xn$ signal, i.e., removing the factor 3 from the pion contribution in (8). Fig. 4c is for the enhanced reggeon exchange, $\lambda_f = 0.6$. Finally, Fig. 4d shows the exponent $n_{eff}(\beta)$ for the pure pomeron exchange evaluated subject to the same $x_{\mathbf{IP}}$-β correlation (11). The impact of the $x_{\mathbf{IP}}$-β correlation is non-negligible for the pure pomeron exchange too. First, the rise of $n(x_{\mathbf{IP}}, \beta)$ with the decreasing β which

is clearly seen in Fig. 3 , transforms into flattening of $n_{eff}(\langle x \rangle = 0.001, \beta)$ and for smaller values of $\langle x \rangle$ into a substantial depletion of $n_{eff}(\langle x \rangle, \beta)$ at small β starting from a fairly large values of β.
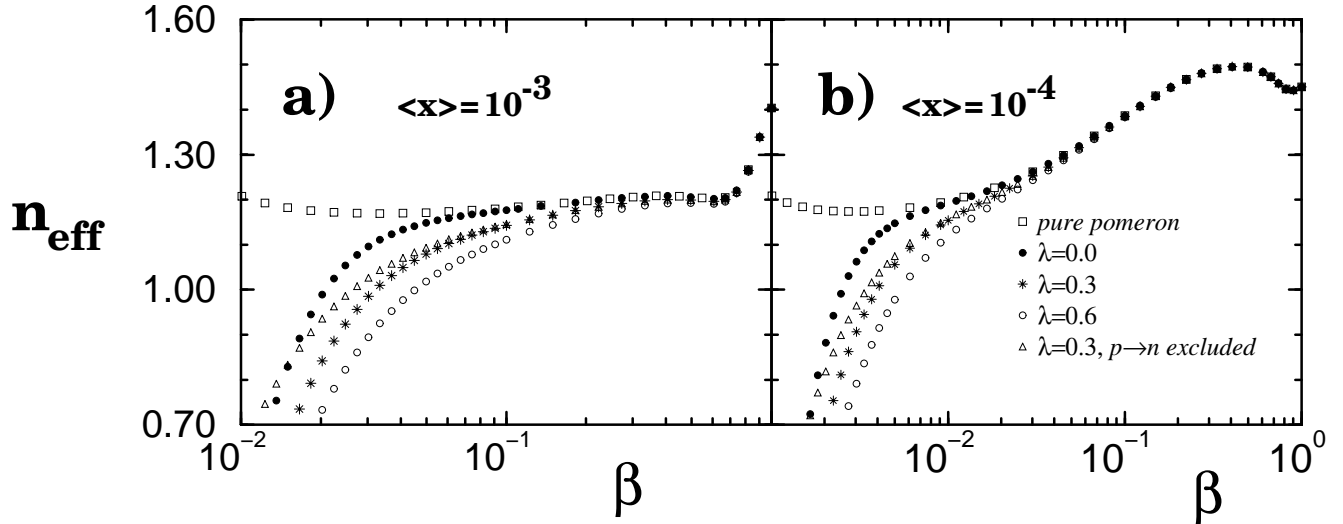

Figure 5: - (a) A comparison of $n_{eff}(\langle x \rangle, \beta)$ evaluated at $\langle x \rangle = 10^{-3}$ for the pure pomeron exchange (squares) and for different assumption on the reggeon and pion exchange; (b) the same as (a) but for $\langle x \rangle = 10^{-4}$. Notice, that the β scales for the two boxes are different.

A more detailed comparison of our results for the pure pomeron exchange and different f and π-exchange background is presented in Fig. 5. In Fig. 5a we take $\langle x \rangle = 10^{-3}$ which is typical of the data taking in the H1 experiment. The allowance for the f-reggeon and pion exchanges leads to a substantial depletion of $n_{eff}(\langle x \rangle, \beta)$ at small β compared to the pure pomeron exchange; the form of the depletion is similar to that reported by H1 [15]. For $\langle x \rangle = 10^{-3}$ we find that the pion contribution affects the exponent n only at $\beta \lesssim 0.05$, the depletion at larger β predominantly comes from the f-exchange. A careful treatment of the $x_{\mathbb{P}}$-β correlation which depends on the experimental acceptances is needed to draw quantitative conclusions on the value of λ_f. One point is clear, though: already in the presently available data the points at largest β are free of the pion and reggeon effects and measure the exponent $n_{eff}(\langle x \rangle, \beta)$ for the pure pomeron exchange. Notice the spike at $\beta \to 1$ in Fig. 5a, which comes from the dominance of the longitudinal structure function at $\beta \gtrsim 0.9$ [8].

5 How to separate the pure pomeron exchange?

The chief purpose of experiments on diffractive DIS is a study of the pomeron exchange and one would like to exclude the reggeon and pion contributions. To this end, recall that even the pion structure function is basically unknown at $x \lesssim 0.2$ and the available parameterization for F_2^π differ markedly [30, 32]. Nevertheless, the pion contribution to F^D can be separated without much problems. Whereas the both diffractive $p \to p$ and charge-exchange $p \to n$ channels do contribute to the present data, the LPS trigger will select the diffractive $p \to p$ channel and lower the pion contribution to the triple-Regge expansion (8) by the factor 3. The effect of the LPS trigger on $n(\langle x \rangle, \beta)$ is shown in Figs. 4b and 5. Furthermore, the Forward Neutron Calorimeters now in operation at the both ZEUS [34] and H1 [35] allow a direct measurement of the charge exchange reaction $\gamma^* p \to Xn$ and then the isospin relation $d\sigma(\gamma^* p \to Xp) = \frac{1}{2} d\sigma(\gamma^* p \to Xn)$ can be used. The LPS and FNC triggers allow a direct determination of the combined effect of all the isovector π, ρ, A_2 exchanges.
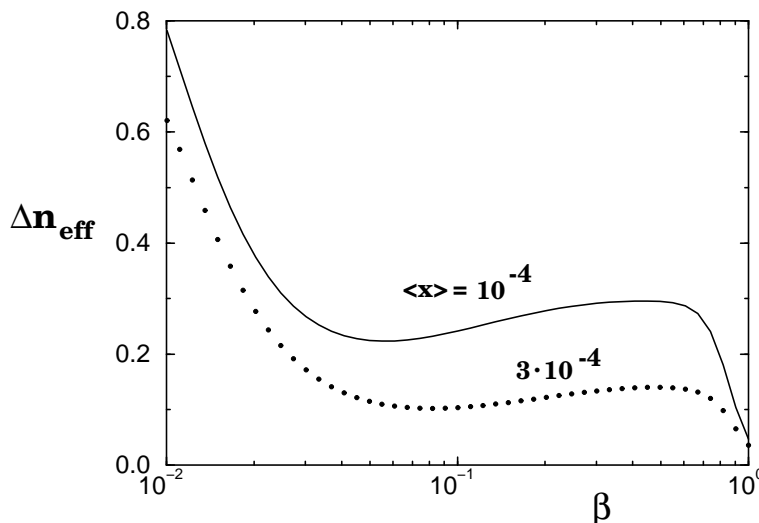

Figure 6: *The change of $n_{eff}(\langle x \rangle, \beta)$ with $\langle x \rangle$ shown in the form of $\Delta n_{eff} = n_{eff}(\langle x \rangle, \beta) - n_{eff}(\langle x \rangle = 0.001, \beta)$.*

An independent direct evaluation of the poorly known f exchange contribution is not possible. The f contribution can be minimized going to smaller values of $\langle x \rangle$ and/or Q^2, which for fixed β implies smaller values of $x_{\mathbb{P}}$. In Fig. 4 we show the effect of changing $\langle x \rangle$, the smaller is $\langle x \rangle$ the weaker is the departure from predictions for the pure pomeron exchange

shown in Fig. 4d. This point is clear from equation (12) and is further demonstrated in Fig. 5b, in which we compare $n_{eff}(\langle x \rangle = 10^{-4}, \beta)$ evaluated for the pure pomeron exchange and with allowance for the reggeon and pion contributions. Going to smaller $\langle x \rangle$ entails smaller Q^2, of course. Here we wish to emphasize that at least in the color dipole gBFKL dynamics properties of the exchanged pomerons do not vary with Q^2 as soon as $Q^2 \gtrsim (2$-$3)\,\mathrm{GeV}^2$ [20]. The principal effect of lowering $\langle x \rangle$ and $x_{\mathbb{P}}$ will be the enhancement of the gBFKL pomeron contribution to the flux factors. The resulting increase of $n(x_{\mathbb{P}}, \beta)$ at small $x_{\mathbb{P}}$ shown in Fig. 3 entails a substantial increase of $n_{eff}(\langle x \rangle, \beta)$ when $\langle x \rangle$ is lowered from $\langle x \rangle = 10^{-3}$ down to $\langle x \rangle = 10^{-4}$. This very specific prediction from the color dipole gBFKL pomeron is best illustrated in Fig. 6, where we show $\Delta n_{eff} = n_{eff}(\langle x \rangle, \beta) - n_{eff}(\langle x \rangle = 0.001, \beta)$ for two values of $\langle x \rangle$. The accuracy of experimental determinations of n_{eff} is already sufficiently high for testing this gBFKL prediction for Δn_{eff}.

6   Conclusions

The triple-Regge phenomenology is called upon for the quantitative interpretation of diffractive DIS as measured in the HERA kinematical domain. Based on the triple-Regge analysis of hadronic diffraction, we formulated expectations for the flux and structure function of secondary reggeons in diffractive DIS. The f-reggeon and pion exchange are the two prominent contributions. We argued that the $\mathbb{P}$-f interference contribution must be small. We find a substantial non-pomeron background, which is strongly enhanced at small β because of the kinematical $x_{\mathbb{P}}$-β correlation. The subasymptotic gBFKL effects also contribute strongly to the observed β dependence of $n_{eff}(\langle x \rangle, \beta)$. The emerging pattern of factorization breaking is consistent with the preliminary data from the H1 experiment. The proposed interpretation of the H1 effect can be tested eliminating the pion (and isovector reggeons in general) background to the pomeron exchange either using the LPS trigger or measuring $\gamma^* p \to X n$ with the forward neutron detectors. Our analysis shows that the large-β results for $n_{eff}(\beta)$ from H1, ZEUS are already free of the reggeon and pion effects and biases for the $x_{\mathbb{P}}$-β correlation and probe the pure pomeron exchange. The f-reggeon contribution will be significantly lowered and will be marginal at $\beta \gtrsim 0.03$ in a data sample taken at $\langle x \rangle \sim 10^{-4}$. A

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substantial rise of $n_{eff}(\beta)$ by ≈ 0.25 over the whole range of β studied experimentally when $\langle x \rangle$ is lowered from $\langle x \rangle \sim 10^{-3}$ down to $\langle x \rangle \sim 10^{-4}$ offers a stringent test of the color dipole gBFKL approach.

After this work was completed, J.Dainton informed us of a related analysis of the H1 data in terms of the f-reggeon exchange [36].

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